ORIGINAL COMMUNICATIONS

Scaphoid nonunion: Role of anterior interpositional bone grafts

Twenty-one cases of unstable fractures of the scaphoid were treated by open reduction, length restoration by interpositional anterior wedge grafting, and fixation with a Herbert screw to obtain union and restore carpal stability. There was primary union in 15 (71%) of 21 patients. Two failed cases were treated with a second anterior wedge graft and Herbert screw fixation; overall rate of union was 81%. Nonunions were related to improper screw placement, failure of compression at the nonunion, bone-graft resorption, or persistent avascular necrosis. In the united scaphoids, carpal instability was corrected, with improvement in the scapholunate angle (65 degrees to 54 degrees) and capitolunate angulations (35 degrees to 15 degrees). Scaphoid malalignment associated with nonunion was improved on biplanar tomographic measurement of the scaphoid angles. (J Hand Surg 1988;13A:635-50.)

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Fracture of the scaphoid is the most common fracture involving the wrist. Studies suggest that only 5% to 10% of these fractures proceed to nonunion, yet a significant volume of literature has been devoted to the problem of scaphoid nonunion. Failure to recognize the original injury, inappropriate or incomplete treatment, and inadequate methods to assess fracture union have been suggested as reasons for the prevalence of scaphoid nonunion. Although not symptomatic initially, most (if not all) nonunions progress to produce a painful wrist with impaired function, clinically significant loss of motion, increased weakness, and degenerative arthritis.

Previous studies emphasized the importance of adequate blood supply, fracture reduction and bone apposition, and firm fracture immobilization in the treatment of scaphoid nonunions. The difficulty of avascular necrosis and nonunion has been addressed with the Russe graft. In the majority of scaphoid nonunions, union rates of 86% to 90% can be anticipated with either palmar inlay (Russe) or dorsal inlay-grafting techniques.

On the basis of these studies, cancellous inlay grafting must be considered the treatment of choice for stable scaphoid nonunions, and in our practice it is the most commonly performed bone-grafting procedure. Recently several authors have described a second category (or type) of scaphoid nonunion that recognizes the importance of displacement of scaphoid fractures. They have pointed out that displaced scaphoid nonunions are more difficult to treat and that they have a lower rate of union than undisplaced scaphoid non-
unions. In addition, the work of Linscheid et al., Fisk, and Fernandez stressed the association of scaphoid nonunion with dorsal carpal instability patterns in which a pathologic dorsal rotation of the lunate is present with an increased scapholunate angle. The ability to identify collapse deformity of the wrist caused by scaphoid nonunions has resulted in recommendations for both palmar and radiopalmar bone grafting of scaphoid nonunions to correct the scaphoid malalignment and to restore normal scaphoid length.

This article describes our experience with unstable scaphoid nonunions and makes recommendations for treatment. We explored the biomechanical features contributing to scaphoid nonunion and on the basis of that information and our own clinical experience report preliminary results of anterior (palmar) wedge grafting and Herbert screw fixation of unstable scaphoid nonunions. We observed that collapse deformity of the wrist resulting from scaphoid fracture requires specific treatment directed at (1) decreasing carpal instability by realigning and lengthening the foreshortened scaphoid, and (2) maintaining the reduction by rigid internal fixation and bone-graft techniques.

### Materials and methods

From October 1982 through June 1984, 21 patients had surgical treatment of unstable nonunions of the scaphoid that were associated with carpal instability. Preoperative assessment included wrist tomography and motion views to assess the degree of carpal instability. If there was greater than 60 degrees of scapholunate and 15 degrees of capitolunate angulation alone or associated with more than 1 to 2 mm of scaphoid fracture displacement, the fracture nonunion was considered to be unstable and open reduction, interpositional bone grafting of the scaphoid, and fracture fixation, with the Herbert screw alone or in combination with Kirschner wires, were performed. The median age of our patients was 22.9 years (range, 16 to 45 years). There were 20 males and 1 female (Table I). Initial treatment of scaphoid fracture was performed in 11 patients (casting in eight and open reduction in three), but there was no treatment in 10 patients. Before our evaluation, surgery had been performed in 10 of the 21 patients. This consisted of Russe bone grafts in five patients, radial styloid inlay grafts in four, and an ASIF screw in one (Table II).

### Table I. Characteristics of patients with scaphoid nonunion

<table>
<thead>
<tr>
<th>Patient (no.)</th>
<th>Age (yr)</th>
<th>Sex</th>
<th>Mechanism of injury</th>
<th>Time from injury (mo)</th>
<th>Symptoms</th>
<th>Motion (E-F-R-U)</th>
<th>Grip (%)</th>
<th>Carpal collapse*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>26</td>
<td>M</td>
<td>Fall</td>
<td>9</td>
<td>Pain, weakness</td>
<td>55-75-10-20</td>
<td>60</td>
<td>Moderate</td>
</tr>
<tr>
<td>2</td>
<td>18</td>
<td>M</td>
<td>Football</td>
<td>8</td>
<td>Pain, loss of motion</td>
<td>50-60-10-20</td>
<td>40</td>
<td>Mild</td>
</tr>
<tr>
<td>3</td>
<td>18</td>
<td>M</td>
<td>Hockey</td>
<td>6</td>
<td>Fatigue</td>
<td>60-80-10-30</td>
<td>70</td>
<td>Mild</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>M</td>
<td>Basketball</td>
<td>24</td>
<td>Pain, loss of motion</td>
<td>50-58-20-30</td>
<td>83</td>
<td>Mild</td>
</tr>
<tr>
<td>5</td>
<td>24</td>
<td>M</td>
<td>Football</td>
<td>60</td>
<td>Failed graft, pain</td>
<td>55-57-20-30</td>
<td>62</td>
<td>Severe</td>
</tr>
<tr>
<td>6</td>
<td>18</td>
<td>M</td>
<td>Basketball</td>
<td>24</td>
<td>Pain with activity</td>
<td>40-65-20-15</td>
<td>†</td>
<td>Mild</td>
</tr>
<tr>
<td>7</td>
<td>34</td>
<td>M</td>
<td>Basketball</td>
<td>48</td>
<td>Reinnjury, weakness</td>
<td>65-70-10-35</td>
<td>78</td>
<td>Moderate</td>
</tr>
<tr>
<td>8</td>
<td>19</td>
<td>M</td>
<td>Fall from horse</td>
<td>9</td>
<td>Delayed union, weak grip</td>
<td>36-30-15-15</td>
<td>40</td>
<td>Severe</td>
</tr>
<tr>
<td>9</td>
<td>17</td>
<td>M</td>
<td>Motorcycle</td>
<td>8</td>
<td>Loss of motion, weakness</td>
<td>26-44-10-20</td>
<td>40</td>
<td>Severe</td>
</tr>
<tr>
<td>10</td>
<td>18</td>
<td>M</td>
<td>Basketball</td>
<td>15</td>
<td>Reinnjury, pain on use</td>
<td>60-65-10-30</td>
<td>60</td>
<td>Mild</td>
</tr>
<tr>
<td>11</td>
<td>18</td>
<td>F</td>
<td>Basketball</td>
<td>6</td>
<td>Pain at extremes of motion</td>
<td>65-75-10-40</td>
<td>58</td>
<td>Moderate</td>
</tr>
<tr>
<td>12</td>
<td>27</td>
<td>M</td>
<td>Logger (fall)</td>
<td>24</td>
<td>Weakness, pain on use</td>
<td>50-60-15-30</td>
<td>87</td>
<td>Moderate</td>
</tr>
<tr>
<td>13</td>
<td>24</td>
<td>M</td>
<td>Roller skating</td>
<td>10</td>
<td>Reinnjury</td>
<td>25-50-10-24</td>
<td>†</td>
<td>Moderate</td>
</tr>
<tr>
<td>14</td>
<td>45</td>
<td>M</td>
<td>Rancher (fall from truck)</td>
<td>12</td>
<td>Pain with hard labor</td>
<td>45-38-10-35</td>
<td>7</td>
<td>Severe</td>
</tr>
<tr>
<td>15</td>
<td>21</td>
<td>M</td>
<td>Frisbee game</td>
<td>12</td>
<td>Pain with activity</td>
<td>75-65-15-25</td>
<td>80</td>
<td>Mild</td>
</tr>
<tr>
<td>16</td>
<td>21</td>
<td>M</td>
<td>Basketball</td>
<td>36</td>
<td>Reinnjury</td>
<td>47-65-15-35</td>
<td>71</td>
<td>Severe</td>
</tr>
<tr>
<td>17</td>
<td>24</td>
<td>M</td>
<td>Motorcycle</td>
<td>6</td>
<td>Reinnjury, pain</td>
<td>Casted</td>
<td>‡</td>
<td>Moderate</td>
</tr>
<tr>
<td>18</td>
<td>16</td>
<td>M</td>
<td>Three-wheeler</td>
<td>3</td>
<td>Delayed union</td>
<td>Casted</td>
<td>‡</td>
<td>Mild</td>
</tr>
<tr>
<td>19</td>
<td>35</td>
<td>M</td>
<td>Football</td>
<td>24</td>
<td>Pain with use, fatigue</td>
<td>60-40-10-40</td>
<td>90</td>
<td>Mild</td>
</tr>
<tr>
<td>20</td>
<td>29</td>
<td>M</td>
<td>MVA</td>
<td>24</td>
<td>Pain, weakness</td>
<td>50-70-23-10</td>
<td>60</td>
<td>Mild</td>
</tr>
<tr>
<td>21</td>
<td>17</td>
<td>M</td>
<td>Football</td>
<td>64</td>
<td>Reinnjury</td>
<td>55-45-20-15</td>
<td>40</td>
<td>Severe</td>
</tr>
</tbody>
</table>

*Carpal collapse: mild, scapholunate angle 55-65 degrees; capitolunate angle 0-10 degrees. Moderate, scapholunate angle 66-75 degrees; capitolunate angle 10-15 degrees. Severe, scapholunate angle > 75 degrees; capitolunate angle > 15 degrees.

†Bilateral fractures.

*Patient seen initially with wrist in cast.

E, Extension; F, flexion; MVA, motor vehicle accident; R, radial deviation; and U, ulnar deviation.
The mechanism of injury was a fall in 4 patients, sports-related injury in 12, and motor vehicle accident in 5. The mean time from original injury to initiation of treatment of scaphoid nonunion was 19.5 months (range, 3 to 84 months). Six patients were seen after they had reinjured their wrist and had persistent pain; previously they were asymptomatic. Presenting symptoms included pain and weakness, loss of motion, pain with heavy labor, decreased grip strength, and fatigue with repetitive work. Findings consisted of snuffbox tenderness, pain in the extremes of motion (especially extension and radial deviation), and occasional...
swelling or crepitus or both. Two patients with displaced, unstable fractures had delayed union. In most patients, preoperative motion was restricted (Table I) and grip strength was decreased to a mean of 62% of normal.

From the preoperative radiographs (anteroposterior, lateral, scaphoid oblique, and trispiral tomography), the presence or absence of an unstable scaphoid nonunion was assessed. The degree of carpal instability was then determined by measuring scapholunate and capitolunate angles on lateral films (Fig. 1). In addition, a new technique to measure malalignment of the scaphoid (Figs. 2 and 3) was introduced preoperatively to determine the size and shape of the proposed interpositional wedge graft and postoperatively to determine the accuracy and adequacy of the open reduction and palmar wedge graft procedures. Scaphoid angulation in the posteroanterior plane was judged by a perpendicular line through the scaphotrapezial joint to a line bisecting the proximal pole of the scaphoid (normal angulation, 30 degrees ± 5 degrees). The preoperative PA tomogram demonstrates 32 degrees of radial angulation. B, Postoperative tomogram demonstrates 22 degrees of angulation.

Scaphoid angulation is measured from perpendicular lines drawn from the articular surface of proximal and distal scaphoid articulation with radioscaphoid and scaphotrapezial joints. On PA tomogram proximal scaphoid line (a-a') bisects the proximal pole between the capitate and radius articular surfaces. The distal scaphoid line (b-b') is drawn perpendicular to the scaphotrapezial joint articular surface. An alternate technique involves lines drawn parallel to the proximal scaphoid articulation with the capitate (c-c') and distal radius (d-d') to judge the position of the proximal scaphoid.
Scaphoid malalignment on lateral films. A, Before operation the angle between proximal scaphoid and distal scaphoid (S-St,) was 36 degrees (normal, 25 degrees ± 5 degrees). B, After operation the lateral scaphoid angulation improved to 24 degrees. On lateral tomograms, the proximal scaphoid line (a-a') is drawn perpendicular to joint articular surface, which can be estimated by either position of lunate (usually dorsally tilted) or the distal radius articulation with the proximal scaphoid. Distal scaphoid line (b-b') is drawn perpendicular to scaphotrapezial joint articular surface.

Perioperative data. To obtain firm internal fixation of the scaphoid, Herbert screws were inserted in the wrist of all 21 patients. The screw length averaged 24 mm (range, 20 to 30 mm). Screws 24 to 26 mm were most common (Table II). In one case, a second screw was inserted because the first screw was thought to be malpositioned, although it provided compression and support. Supplemental Kirschner wires were inserted in the wrist of 17 of the 21 patients, usually to reduce dorsal angulation of the lunate before scaphoid reduction and bone grafting. In several patients, two Kirschner wires were inserted: one to stabilize the proximal carpal row (proximal scaphoid and lunate) and the other to support the scaphoid bone-graft site during screw insertion. Iliac crest was the bone-graft source in 17 patients and the radial styloid in 4. The iliac crest graft was a bicortical graft taken with an oscillating Microaire (Microaire Saw, Surgical Instruments, Inc., San Fernando, Calif.) saw to the precisely measured height, width, and length of the needed interposition bone graft. Immobilization after operation was always used and involved a long arm cast in 10 patients and a short arm...
Fig. 4. A, Longitudinal axis of scaphoid lies across colinear axes of lunate and capitate on radiocapitate ligament. B and C, Compressive forces on distal and proximal scaphoid are equal but of opposite direction. When bending moments are compared in relation to the fulcrum over which the scaphoid rests, it can be seen that the scaphoid is acted on by a force couple. This force couple tends to induce a palmar rotation of the distal portion of the fractured scaphoid, which results in widening of the fracture dorsally and coaptation palmarly.

There is a definite propensity for the lunate to assume the extended position after either rupture of the scapholunate interosseous membrane or, in this case, scaphoid fracture; some persons show more tendency for the midcarpal joint to collapse into the extended intercalated pattern than do others. Extension of the lunate tends to carry the proximal pole of the scaphoid with it, preventing adequate bone apposition at the fracture site—an unstable scaphoid nonunion. When viewed in the anteroposterior (frontal) plane (Fig. 4, E through G), the same joint compressive forces induce radial angulation at the fracture site and result in radial malangulation of the scaphoid. Thus, the net effect of the joint compressive forces acting on the fractured scaphoid induces dorsal and radial angulation at the fracture site and limited apposition of the fracture surfaces. Dorsal and radial osteophytes may form and be noted clinically as the scaphoid “humpback” deformity and the dorsal intercalary segment instability (DISI) collapse pattern of wrist instability (Fig. 4). The consequence of coaptation at the palmar aspect of the scaphoid over a prolonged period is increased bony resorption and erosion, overall loss of length of the palmar surfaces of the scaphoid, and further malangulation of the fracture fragments.

A final factor in nonunions of the scaphoid is the tendency of the capitate to push the lunate and triquetrum ulnarly, taking the proximal scaphoid fragment with them.

**Surgical technique**

On the basis of preoperative evaluation and planning, either a palmar or radial approach to the wrist was used (Fig. 5, A through C). The palmar approach is a distal extension of the Russe incision, with the interval between the flexor carpi radialis and radial artery developed from the wrist crease to the thumb base. The palmar radioscapholunate and radiocapitate ligaments are divided and the exposure is extended distally to the scaphotrapezial joint. The radial approach, which uses the interval between radial artery and first extensor compartment palmarly and extensor pollicis longus dor-
The site was identified, and the wrist capsule was incised through the interval between flexor carpi radialis (ulnar) and abductor pollicis longus radially. Radial artery and its lateral palmar branch should be carefully identified. Palmar wrist capsule is divided in line with incision. After resecting the scaphoid nonunion site, trapezoidal bicortical-cancellous graft from iliac crest is fashioned and inserted across nonunion site. Rigid fixation is achieved by Herbert screw inserted with compression, distal to proximal, from distal scaphoid across bone graft into proximal fragment of scaphoid. (By permission of Mayo Foundation.)

With the scaphoid exposed (Fig. 6, A through C), the nonunion site was resected back to viable bleeding bone with a Micro-aire saw (3 mm blade). To correct the scaphoid collapse deformity and to increase the bone apposition area for scaphoid healing, the carpal insta-
Fig. 6. C-D. C, Palmar approach (extended Russe) between flexor radialis and radial artery to scaphotrapezial joint. Note displaced scaphoid nonunion. D, Lunate and proximal scaphoid are reduced and stabilized with Kirschner wire. Retractor helps hold reduction in place.

Fig. 6. C-D. C, Palmar approach (extended Russe) between flexor radialis and radial artery to scaphotrapezial joint. Note displaced scaphoid nonunion. D, Lunate and proximal scaphoid are reduced and stabilized with Kirschner wire. Retractor helps hold reduction in place.

bility was corrected by derotating the extended lunate and with it, the proximal scaphoid (Fig. 6, D). The lunate was pinned in the corrected position with a transfixing Kirschner wire. The size of the wedge graft was determined from direct measurements of length, width, and breadth and compared with preoperative measurements of the opposite, normal wrist or tomograms of the involved wrist.

A bicortical corticocancellous graft was harvested from the patient’s opposite iliac crest or ipsilateral distal radius by use of a micro-sagittal saw. The graft was inserted across the nonunion site and sculptured to fit the defect, avoiding abutting or overhanging fragments. A Kirschner wire was inserted to stabilize the graft and anteroposterior and lateral films were obtained (Fig. 6, E through F). If the reduction was suitable, the Herbert jig was adjusted to fit onto the tuberosity of the scaphoid (Fig. 6, G). Release of the scaphotrapezial joint was usually necessary and a small elevator was used to displace the entire scaphoid radially to apply the Herbert jig. A second film (Fig. 6, H through J) is recommended (in two planes) to double-check the alignment of jig placement to avoid erroneous screw insertion.

Insertion of a Herbert screw was done after the prescribed techniques.20 We prefer to leave the Kirschner wires in place to help maintain the reduction of the scaphoid and lunate (Fig. 6, J). Loss of alignment and loosening of the proximal fragment of the scaphoid have occurred both during and after insertion of the Herbert screw in the absence of Kirschner wire fixation because of screw twisting and loosening within the hard proximal pole. Closure of both scaphotrapezial and radio-
Fig. 6. E-G. E, Anteroposterior (AP) and F, lateral films confirm accurate reduction of scaphoid and lunate. G, Herbert jig application at distal scaphoid after mobilization of scaphotrapezial joint.

carpal joint capsules and ligaments was performed, and the wrist was immobilized in a supportive splint until a thumb spica cast was applied. Cast immobilization continued until tomograms confirmed fracture union (Fig. 6, K through L). Kirschner wires were removed generally by the fourth to sixth week.

Results

The results of patient treatment demonstrated a fracture union rate of 71% (15 of 21). Three patients had additional bone grafting and achieved union for an overall union rate of 86% (18 of 21). In the initial successful cases, union was achieved in a mean of 4.3 months (range, 3 to 12 months). Of the three patients with additional bone grafting, one patient (no. 1) required revision with a second anterior wedge graft and Herbert screw internal fixation and had union at 15 months from the time of initial treatment. A second patient (no. 9) had revision with a palmar Russe interposition graft and Kirschner wire internal fixation (the loose Herbert screw was removed). A third patient (no. 21) has union with a second palmar wedge graft and Herbert screw after the initial procedure, a Russe graft, was unsuccessful and after the original Herbert screw loosened in a second football injury.

The other three fractures remain ununited. One patient (no. 7) had a retrograde or proximally inserted Herbert screw for a proximal pole fracture and has an
asymptomatic fibrous nonunion. The second and third patients (no. 5 and 13) have persistent nonunions, with the Herbert screw in place, but they are also asymptomatic to the point that they have refused further operative treatment.

In the 18 cases with scaphoid union, the range of motion averaged 47 degrees of extension, 50 degrees of flexion, 14 degrees of radial deviation, and 27 degrees of ulnar deviation. Achieving union was at the cost of wrist motion, since this represented a loss of 10% of extension and 26% of flexion compared with preoperative range of motion. However, grip strength increased from 62% to 75% of the uninjured side in cases in which there was satisfactory fracture healing.

It appeared that the use of internal fixation with Kirschner wires had a beneficial effect on stabilization of the nonunion site and correction of the DISI deformity because there was improved carpal alignment after corrective bone-graft procedures. The length of cast immobilization was 3.5 months (range, 1 to 5 months) and there was no significant difference between a long arm cast and a short arm cast and eventual fracture healing.

Nonunions of the scaphoid after anterior wedge grafting and Herbert screw insertion were related to improper screw placement, bone-graft resorption, and factors related to the long-term carpal instability. Inadequate screw insertion occurred in four patients and led...
to incomplete fracture stabilization. Difficult insertion of the Herbert screw within the more proximal fragment was reported by the operating surgeon in three of six cases and may have led to nonunion. Bone-graft resorption occurred in four patients (Fig. 7, A through G) and was associated with nonunion in two of the four patients (radiographic analysis). There was a correlation between delayed or eventual lack of fracture healing and the difficulty in obtaining satisfactory correction of long-term carpal instability.

**Results based on radiographic analysis.** From radiographic measurements of preoperative and postoperative biplanar tomograms, we were able to assess the improvement in carpal instability and the changes in scaphoid alignment after anterior wedge grafting. Carpal indices (normal, 0.54 ± 0.03) were improved: preoperative carpal index of 0.51 (range, 0.46 to 0.54) to a postoperative carpal index of 0.54 (range, 0.51 to 0.58), with an average improvement of 0.03. Carpal instability was corrected as demonstrated by an improved scapholunate angle: preoperative mean of 65° and postoperative mean of 54°. The capitolunate angulation also improved from a mean of 15° preoperatively to a mean of 3.5° postoperatively (Table III).

Fig. 7. An 18-year-old student sustained bilateral scaphoid fractures from a fall while playing basketball. A, Anteroposterior (AP) and B, lateral views show failed ASIF screw fixation of left wrist performed 2 months after original injury. C, AP tomogram demonstrates cystic resorption about short screw; S-S, angulation of 35 degrees.

A second serious complication was bone-graft resorption or extrusion (Fig. 8, B), which occurred in 4 patients who had failed to achieve union with this technique (Fig. 8, A). Of these, there was a delay of more than 4 years before this procedure was used in three of the six patients, suggesting that fixed carpal instability may have contributed to the nonunion rate.

**Complications.** Complications from palmar wedge grafting associated with fixation by a Herbert screw were related to technical factors encountered in our attempts to correct fixed or long-established carpal instability. Moderate-to-severe carpal instability was present in five of six patients who had failed to achieve union with this technique (Fig. 8, A). Of these, there was a delay of more than 4 years before this procedure was used in three of the six patients, suggesting that fixed carpal instability may have contributed to the nonunion rate.

A second serious complication was bone-graft resorption or extrusion (Fig. 8, B), which occurred in 4
of the 21 patients. Two of these patients had complete resorption (no. 7 and no. 13) leading to nonunion with failure of the wedge-grafting technique. Two patients had partial resorption (no. 6 and no. 11), but both cases resulted in fracture union. Partial graft extrusion (Fig. 8, C) may have contributed to the resorption process in the latter two cases but fortunately it was not significant enough to prevent fracture healing.

Avascular necrosis (Fig. 8, D) was present in 10 of the 21 patients preoperatively and had resolved completely in 4 patients postoperatively. Of the remaining six patients, two have radiographic evidence of avascular changes with signs of improvement and four have persistent avascular necrosis associated with fracture nonunion. Two of these four patients have had a subsequent inlay or anterior wedge bone-grafting procedure.

Problems related to the insertion of the Herbert screw with malplacement of the screw have also been encountered (Fig. 8, E). Screw placement either outside of the scaphoid or within the scaphoid, but not applying compression, occurred in four patients. Two of these placements resulted in loose screws that were removed. Screw removal was also necessary in two of the patients with scaphoid nonunions that went on to secondary bone-grafting procedures.

Discussion

Gilford, Bolton, and Lambrinudi first recognized the importance of the unstable scaphoid nonunion; Fisk later heralded this as an important principle in the treatment of scaphoid fractures. In Fisk’s discussion of the unstable scaphoid nonunion, he referred to it as the “unsolved fracture.” He believed that an effort should be made to correct the associated carpal instability, which he called “concertina collapse deformity,” and for this he recommended a radiopalmar interposition bone graft accompanied by internal fixation. He noted that an anterior wedge graft dramatically restored the length of the scaphoid and abolished the concertina deformity, resulting in stabilization of the wrist. Linscheid, Dobyns, and Cooney reported on six cases of palmar wedge grafting that used a similar technique in which a bicortical iliac graft was impacted between the fragments of the scaphoid. Internal fixation was done with Kirschner wires. This procedure involved a
In the current operative procedure, the technique of anterior wedge grafting has been combined with internal fixation with a Herbert screw in an effort to maximize the degree of intercarpal collapse, and the normal scapholunate and capitulonate angles. A triangular or trapezoidal graft was used in his series of six cases to bridge the nonunion defect. He thought that correction of carpal instability with Kirschner wire fixation of the lunate was not indicated.

In the current operative procedure, the technique of anterior wedge grafting has been combined with internal fixation with a Herbert screw in an effort to maximize correction and fracture stability. The results indicate that there is improvement in the carpal instability after this procedure and that primary union was achieved in 15 (71%) of 21 patients. These results of treatment are not dissimilar to those reported by Fisk in which he obtained union in 27 (73%) of 37 nonunions. The concept of using Herbert screw fixation for this fracture was stimulated by a paper presented by Herbert at the Eleventh Combined Meeting of the Orthopaedic Associations of the English-Speaking World after another paper on palmar wedge grafting of scaphoid nonunions by one of us (R. L. L.). The application of a double-canted screw, which will allow compression across the fracture site, combined with a palmar wedge graft, appeared to have significant advantages over conventional techniques for the management of the ununited, unstable scaphoid fracture. In a subsequent publication, Herbert and Fisher reported their own overall results with this technique: 77 cases of type D fractures (sclerotic, established scaphoid nonunions). Internal fixation combined with bone grafting was indicated if the patient had significant symptoms or was at risk of developing secondary degenerative arthritis in the radiocarpal joint. The series by Herbert and Fisher had a 70% union rate (54 of 77) and was noteworthy in that several patients were treated more than 18 months after the original injury, previous bone-graft operations had been performed, and many proximal-pole fractures with sclerotic bone were present.

In our analysis of scaphoid nonunion treated with anterior wedge grafting, we were able to demonstrate not only reasonably satisfactory fracture healing but...
Fig. 8. Complications of palmar wedge grafting with Herbert screw fixation. A, Uncorrected carpal instability with persistent “humpback” collapse deformity and fracture nonunion. B, Graft resorption, primarily palmar-ulnar (50%) related to over-compression with Herbert screw. Screw loosening occurred secondarily. C, Graft extrusion and nonunion secondary to loss of proximal screw fixation 6 months after operation. D, Proximal pole avascular necrosis associated with nonunion. Note loose proximal screw threads. E, Two screws transfix the scaphoid in a large patient with previous Russe graft, collapse deformity, and avascular necrosis. Although one screw appears outside the scaphoid, the patient was asymptomatic; the scaphoid was united.

also improved carpal alignment associated with this procedure. Unfortunately the operative technique is not easily performed and intraoperative complications, including malposition of the internal fixation screw, have been reported. Analyses of our results suggest that a radial (Dobyns approach) rather than palmar approach might be preferable in those cases in which one can clearly identify a dorsal humpback deformity so that a biplanar radial- and palmar-placed graft could be inserted. The “humpback” deformity, which can be associated with long-standing scaphoid nonunions, should be excised to achieve proper reduction and adequate placement of the interposition wedge graft. If intraoperative difficulties are encountered in inserting the Herbert screws, we think that the procedure should be abandoned in favor of internal fixation with multiple Kirschner wires. We are concerned about the problem of bone-graft resorption that developed in 4 of the 21
patients presented in this series and that has occurred more recently in 3 additional patients. In these cases of graft resorption, union of the bone graft occurred distally but not proximally. Therefore, we question those who advocate the use of the anterior wedge grafting technique with Herbert screw (or any internal screw) in patients with avascular necrosis of the proximal pole of the scaphoid. The conventional Russe-type procedure with removal of avascular sclerotic bone might be more appropriate in the presence of avascular changes of the proximal scaphoid.

Conclusions

Anterior palmar wedge grafting of the scaphoid should be considered for symptomatic nonunion of the scaphoid associated with carpal instability. When combined with a Herbert screw, it can provide a satisfactory rate of union in these difficult, unstable nonunions. In addition, it provides the opportunity for improving normal scaphoid alignment and, as a result, permanent improvement in carpal instability. It is indicated in preference to the more traditional Russe technique when there is carpal instability, as demonstrated by increased scapholunate angle (>60 degrees), capitulunate angulation (>15 degrees), and scaphoid malalignment on posteroanterior and lateral radiographs. We believe that it is best to achieve union of the scaphoid by these reconstructive efforts and have preferred repeat open reduction and internal fixation techniques to partial or total scaphoid excision or Silastic replacement. The natural history of scaphoid nonunions has demonstrated an almost universal occurrence of degenerative arthritis when there is an associated collapse deformity of the wrist. When carpal instability is identified in patients with nonunions of the scaphoid, we recommend this anterior (or anterolateral) wedge graft technique in an effort to restore normal length to the scaphoid, correct carpal instability, and, hopefully, prevent late degenerative arthritis. Use of the Herbert screw in these cases must be done with caution and is contraindicated if there are avascular changes in the proximal fragments of the scaphoid. One must be well acquainted with the technical factors associated with the use of this internal fixation equipment to prevent complications associated with its use.

REFERENCES

The carpal bones in congenital hand anomalies: A radiographic study in patients older than ten years

Abnormalities of the carpal bones in 192 anomalous hands of 154 patients older than 10 years were examined. Judging from the time of appearance of the pisiform, there was no delay of carpal bone maturation in these anomalies. There were differences between the carpal bones of three distinct groups: which included central polydactyly, syndactyly, and typical cleft hand; the group which included radial and ulnar deficiency, and the group which included symbrachydactyly and transverse defect. This suggests that there were differences between these groups in the timing and degree of injury to the limb bud or the hand plate in the course of development. It is thought that the first group originates from maldistribution of mesenchymal tissue of the limb bud (or of the apical ectodermal ridge), the second group from defects of that tissue, and the last group from defects of the mesenchymal tissue of the hand plate. (J HAND SURG 1988;13A:650-6.)

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Although many radiographic studies of hand anomalies have been done, there have only been a few systematic studies that emphasized the carpal bones and some sporadic studies concerning specific hand anomalies. We studied the x-ray films of the carpal bones of congenital hand anomalies of patients older than 10 years and examined the relation between the carpal bone deformities and their developmental course.

Table I. Typical cleft hand

<table>
<thead>
<tr>
<th>Type of defect</th>
<th>Carpal bone abnormality</th>
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<tbody>
<tr>
<td>Distal</td>
<td>+</td>
</tr>
<tr>
<td>Proximal†</td>
<td>4 hands</td>
</tr>
<tr>
<td>Partial defect of metacarpus</td>
<td>10 hands</td>
</tr>
<tr>
<td>Complete defect of metacarpus</td>
<td>5 hands</td>
</tr>
</tbody>
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*Defects the digital ray from the proximal phalanx.
†Defects the digital ray including the metacarpus.

Materials and methods

One hundred ninety-two hands of the 154 cases seen at our clinic between 1963 and 1986 were reviewed radiographically. They included duplicated thumb, polydactyly, syndactyly, typical cleft hand, triphalan-